LUNAR DUST CHARGING BY PHOTOELECTRIC EMISSIONS: L*evitation, Adhesion & Transportation*

Mian Abbas

NASA-Marshall Space Flight Center

LUNAR DUST CHARGING BY PHOTOELECTRIC EMISSIONS: *Levitation, Adhesion & Transportation*

Co-Investigators:

P. D. Craven[1], D. Tankosic[2], J. F. Spann[1], R. B. Hoover[1], A. LeClair[1], & E. A. West[1]

[1]NASA-Marshall Space Flight Center

[2]University of Alabama in Huntsville

Acknowledgements:

The lunar dust grains employed in this work were provided by Larry Taylor of Univ. of Tenn. We are grateful to Frank Six, John Davis, and Ron Koczor for support of this work under the CDDF-IRAD program. Thanks are due to C. Ryland, J. Redmon, V . Coffey, & N. Martinez for assistance in the laboratory set up.

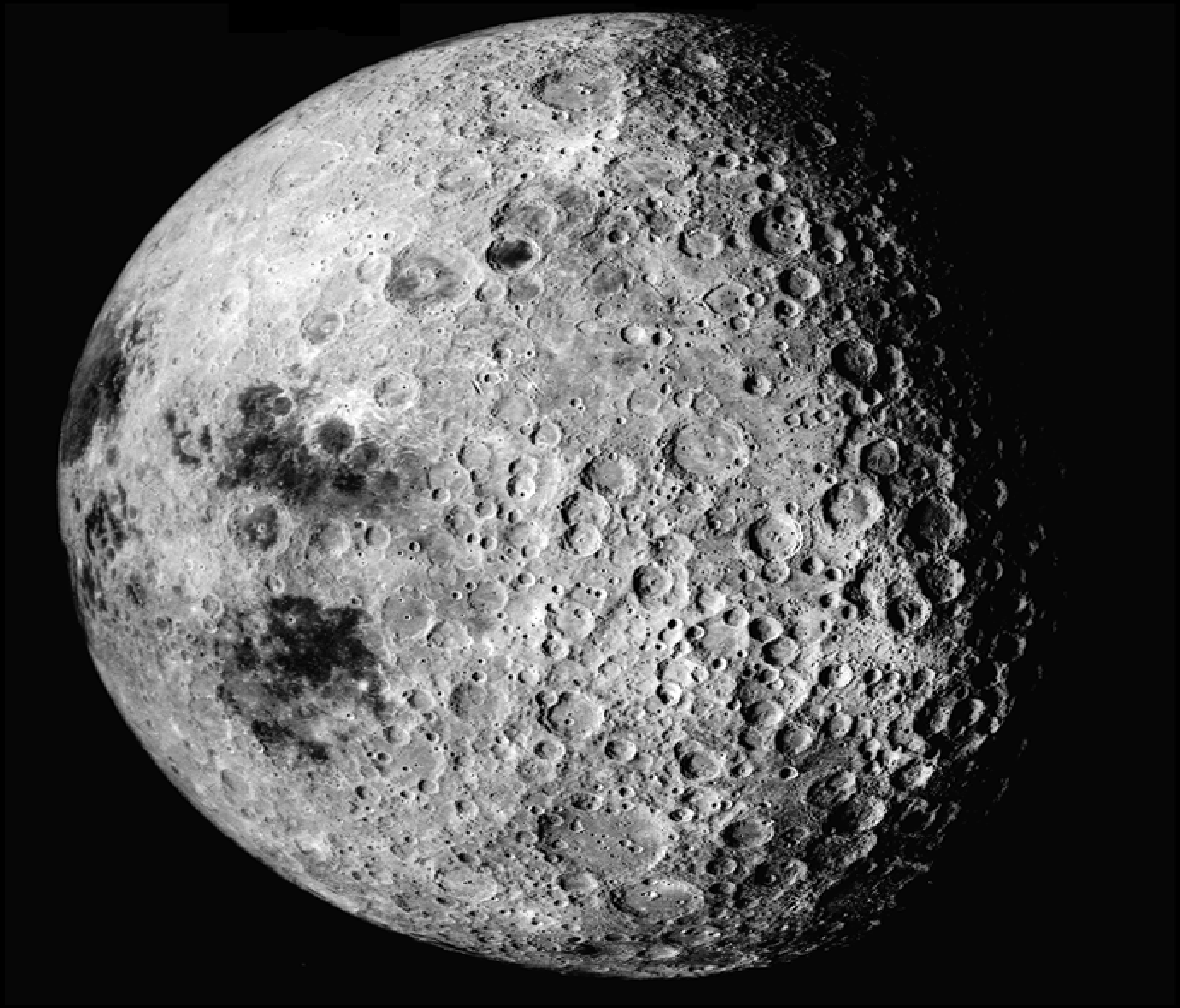
Basic Lunar Data

- Pressures ~ 10^{-12} torr
- Surface Temperature: T ~ 120 to 395 K during the month long lunar day; In polar regions T ~ 80 K

- Mean Radius: 1737.4 km; Mass: 0.012 (Earth=1)
- Gravity ~ 1/6th of the Earth; Density: 3.34 (g/cm^3)

- Orbit Period: 27.32 (Earth days)
- Synchronous Rotation Period: 27.32 (Earth days)
- Semi-major Axis of Orbit: 384,400 km
- Eccentricity of Orbit: 0.055

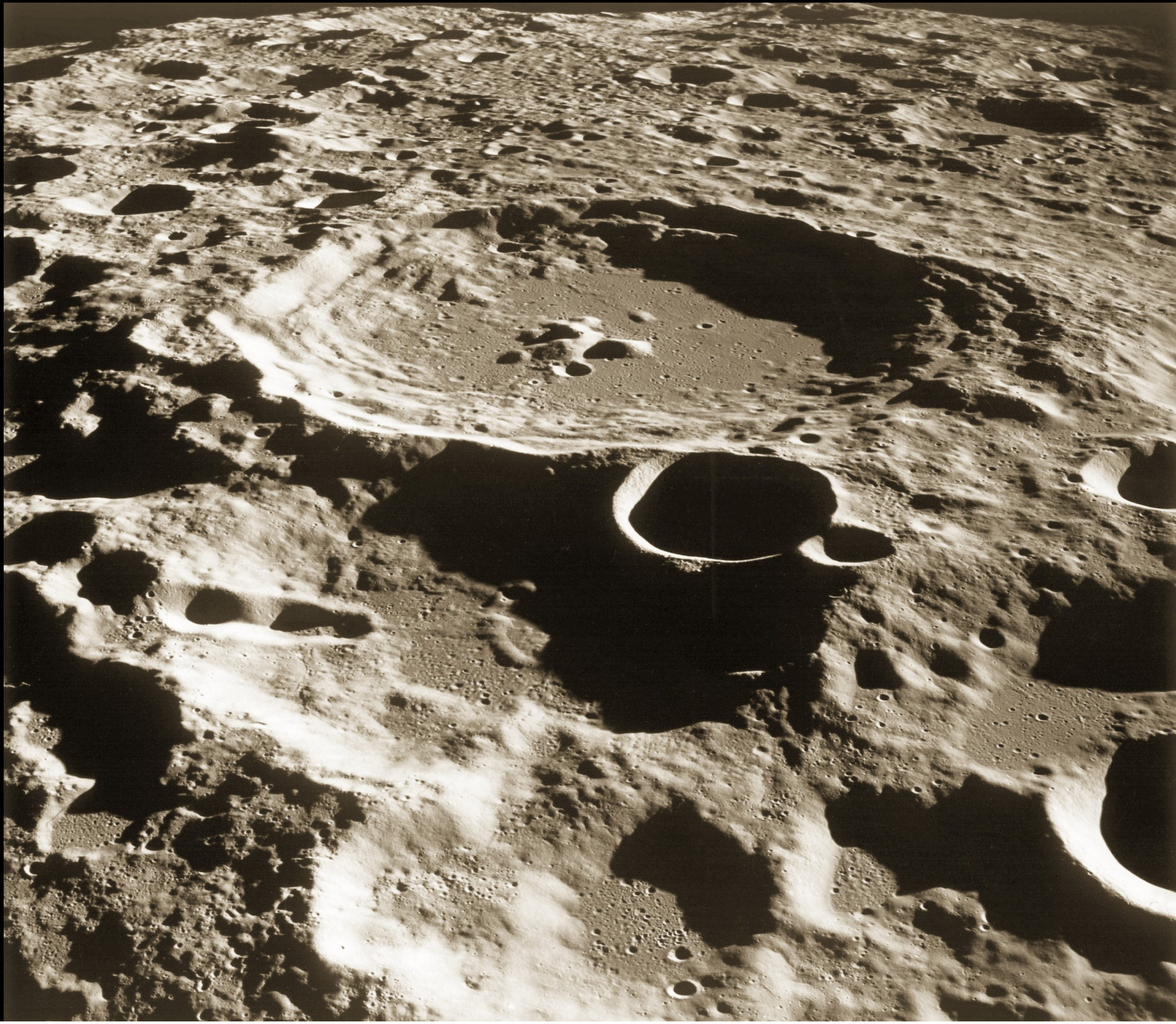
Heavily Cratered Far-Side of the Moon – Apollo 11



Heavily Cratered Far-Side of the Moon

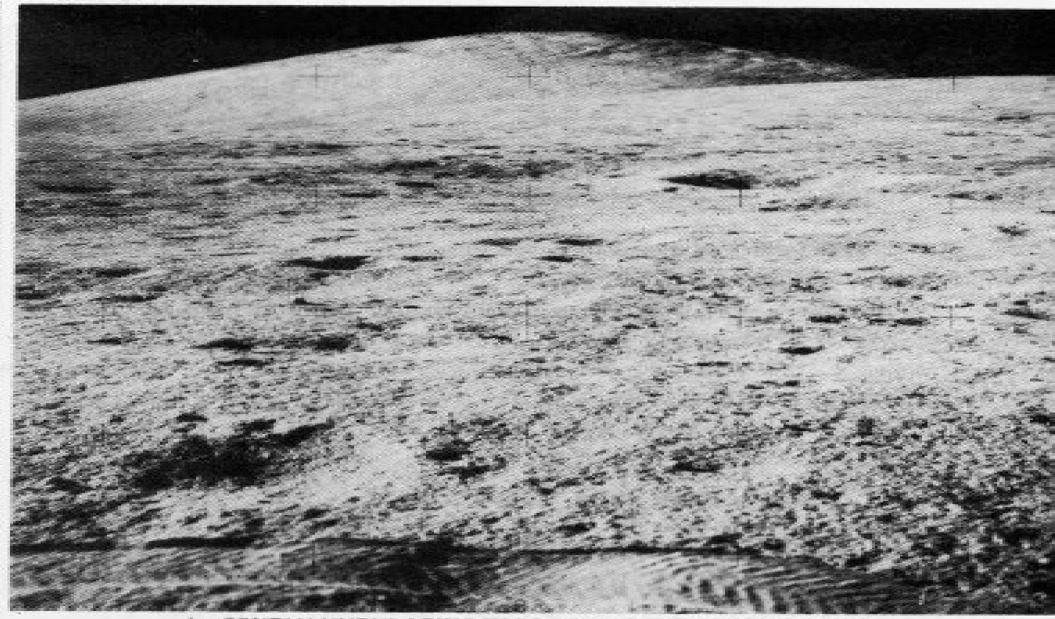
Image by Apollo 11 1969, shows a portion of the Moon's heavily cratered far side,

~ 80 km in diameter.

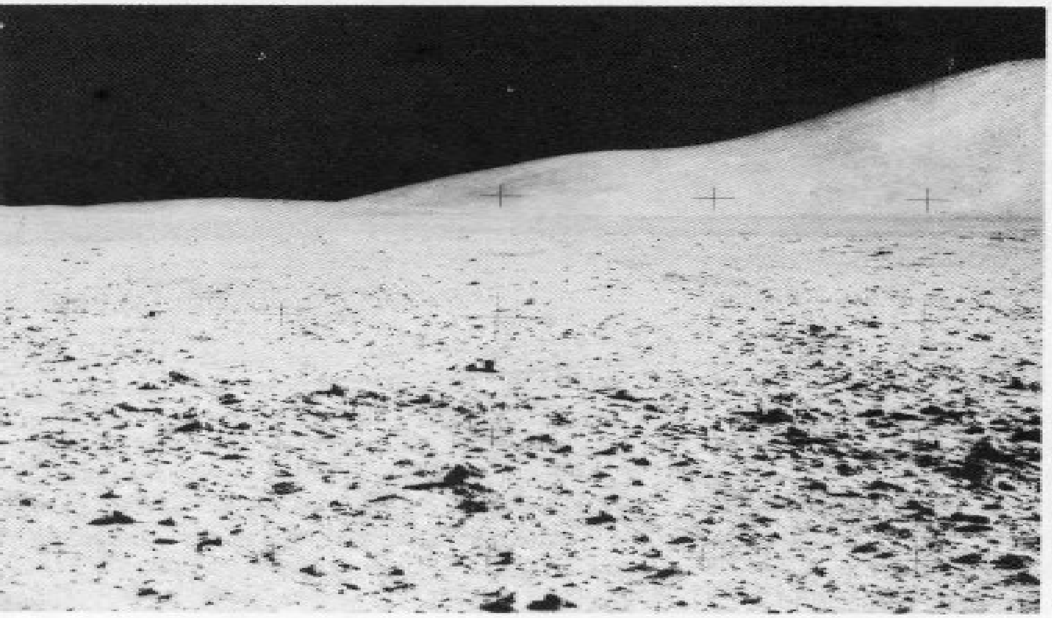


Dusty Environment on the Moon

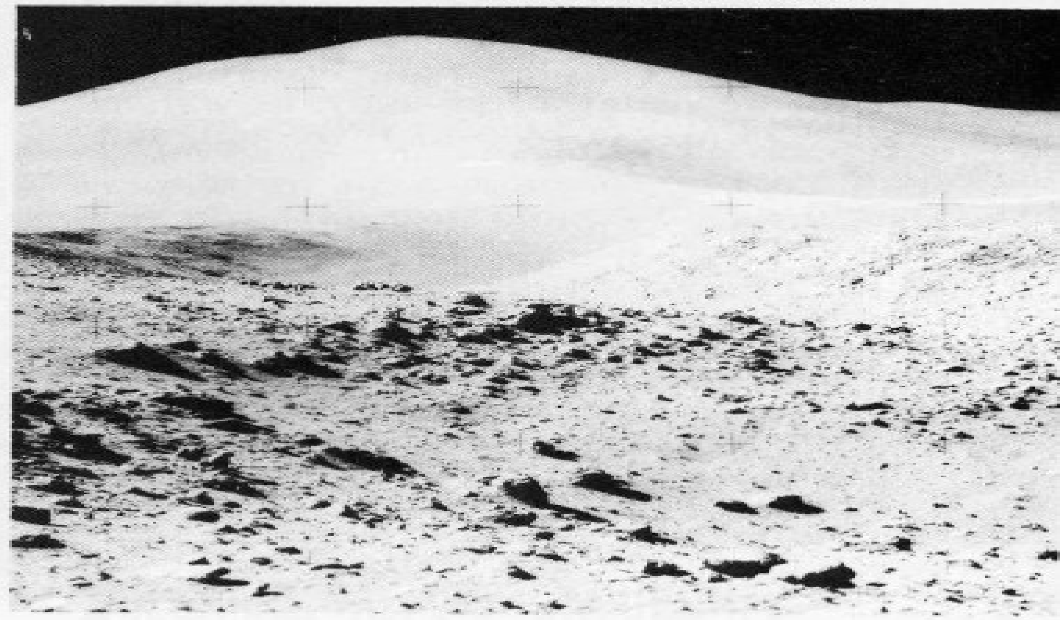
a. SMOOTH MARE, VIEWED FROM STATION 8, EVA II



b. GENTLY UNDULATING TERRAIN NEAR STATION 2, EVA I



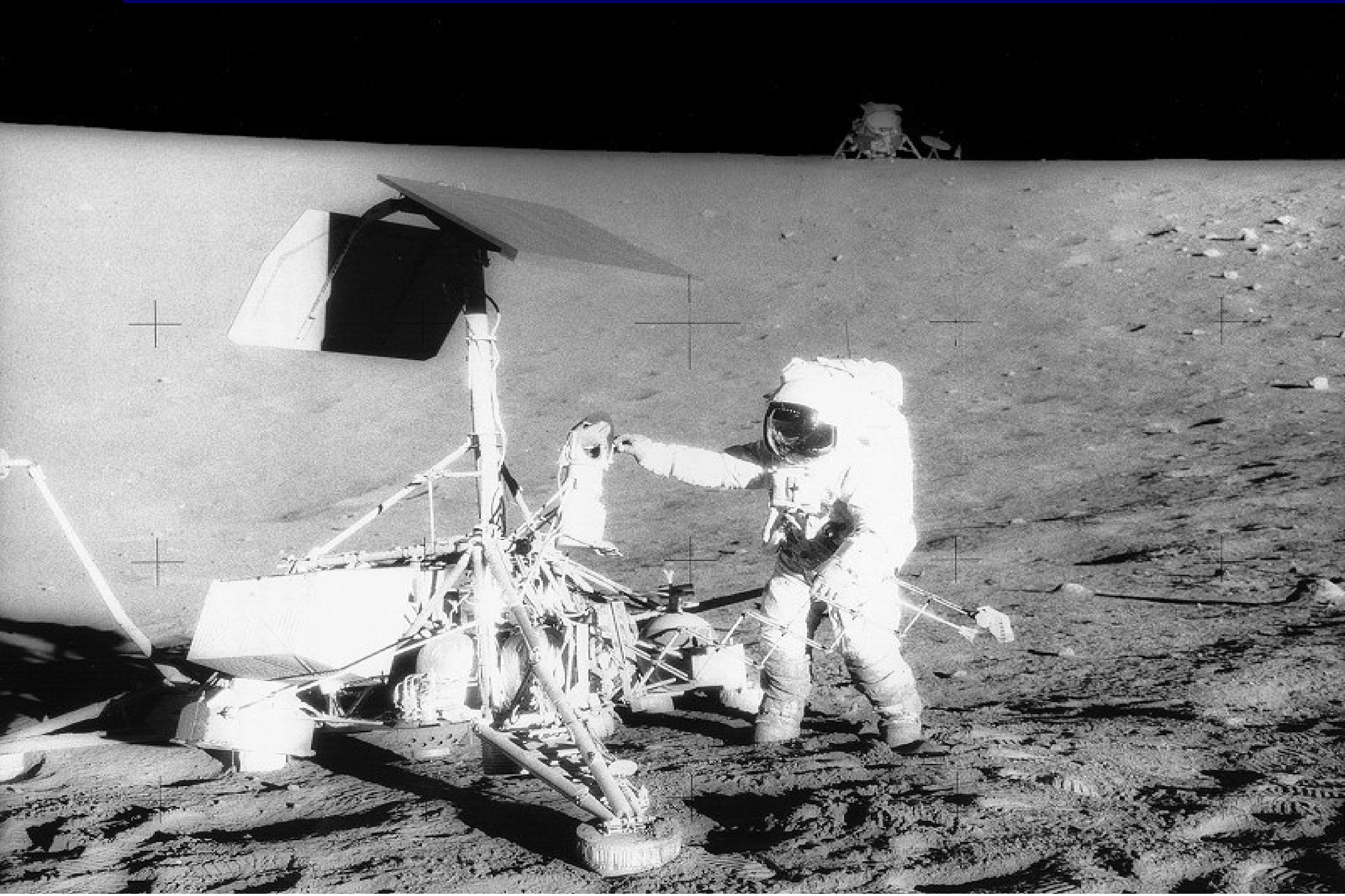
c. SPARSE BOULDER FIELD (BOULDER SIZE 15 TO 20 CM) NEAR STATION 9, EVA III
NOTE LRV TRACKS IN THE MIDDLE OF THE PHOTO.



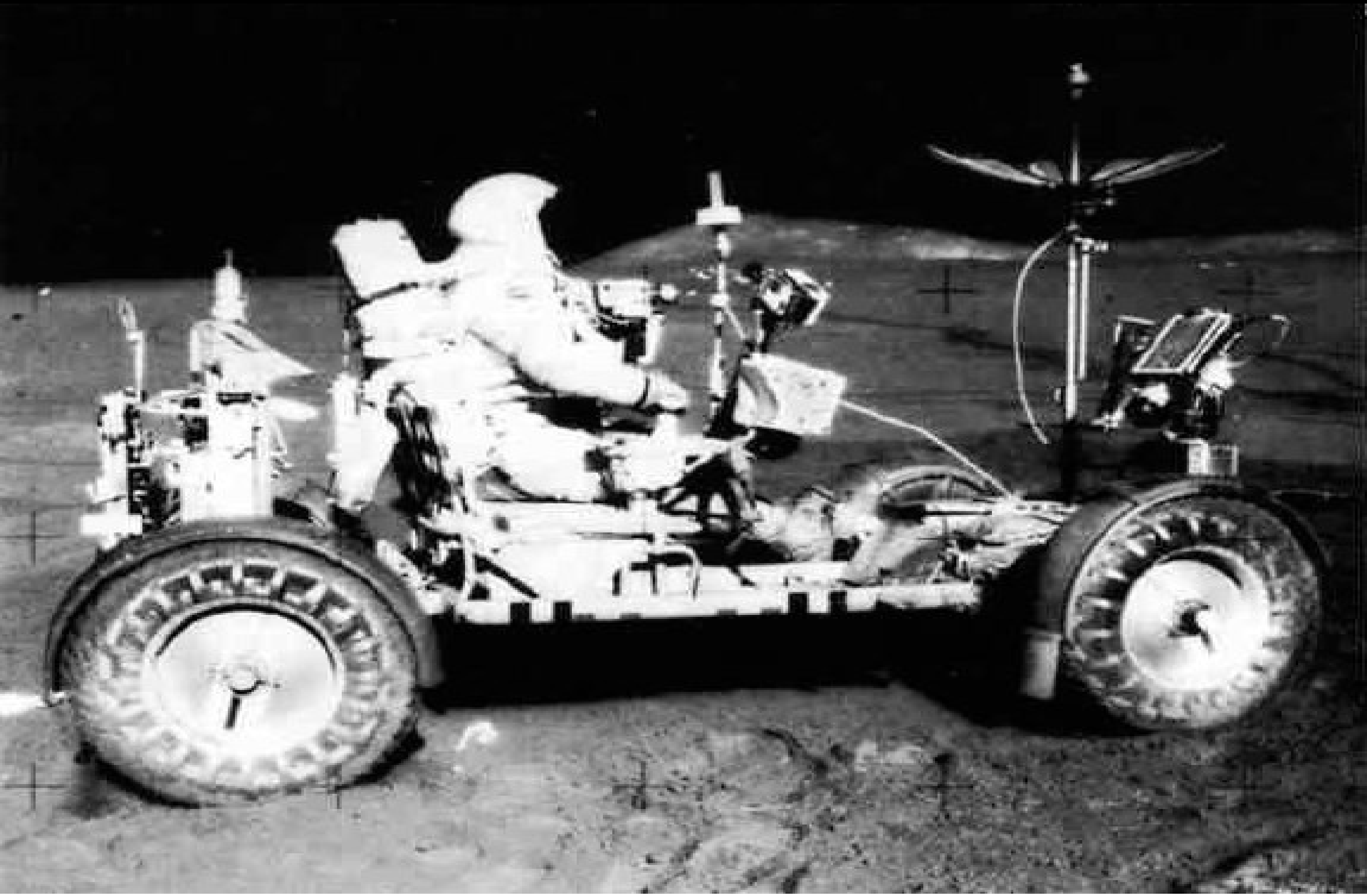
d. BOULDER FIELD AT THE RIM OF HADLEY RILLE

Figure 17. Increasing levels of lunar surface roughness at Hadley-Apennine region.

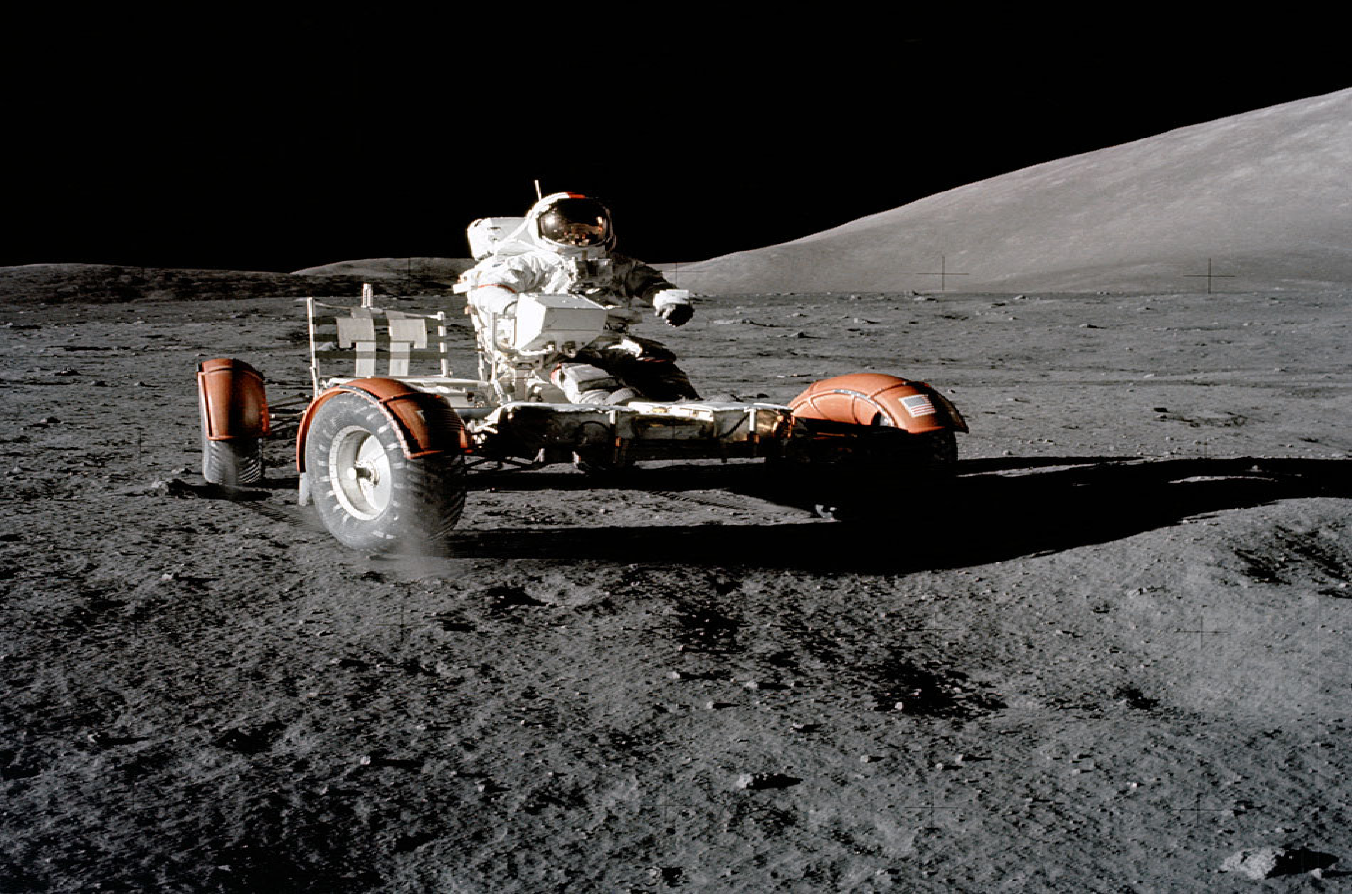
Dusty Environment on the Moon



Dusty Environment on the Moon



Dusty Environment on the Moon



Observed Lunar Dust Phenomena

- The astronauts found the lunar dust to be unexpectedly high in its adhesive characteristics, sticking to the suits, instruments, and the lunar rover.

- Lunar Surveyor Spacecrafts, and the Lunar Ejecta & Meteorite Experiment on Apollo 17 indicated the presence of transient dust clouds in the lunar environment.

- A horizon glow over the lunar terminator and high altitude streamers were observed by the astronauts on the Apollo 17 spacecraft.

- This glow phenomenon was observed during the lunar sunrise and sunset by astronauts both on the surface and in the spacecraft in orbit, and was recorded in their logbooks.

- In the more recent mission, the Clementine Spacecraft (1994) has also detected the lunar glow phenomenon at high altitude.

Lunar Regolith Formation Processes

- The lunar regolith is formed by impact of meteorites, high velocity micrometeorites, cosmic rays, and the solar wind over billions of years.
- Composed of irregularly shaped fine and coarse dust grains with size distribution in the range of nano-meter, sub-micron, centimeter size or larger.
- With virtually no atmosphere, the lunar regolith is exposed to the intense unimpeded solar electromagnetic radiation in the visible, UV, and x-ray spectral regions, as well as charged particle radiation that includes high energy (1-10 GeV/nucleon) galactic cosmic rays, and the solar wind.

Lunar Regolith Formation Processes

- **Agglutinates:** Individual small particles (< 1mm) formed as aggregates from smaller particles produced at high temperatures in the lunar soil by meteoritic impact at very high velocities.

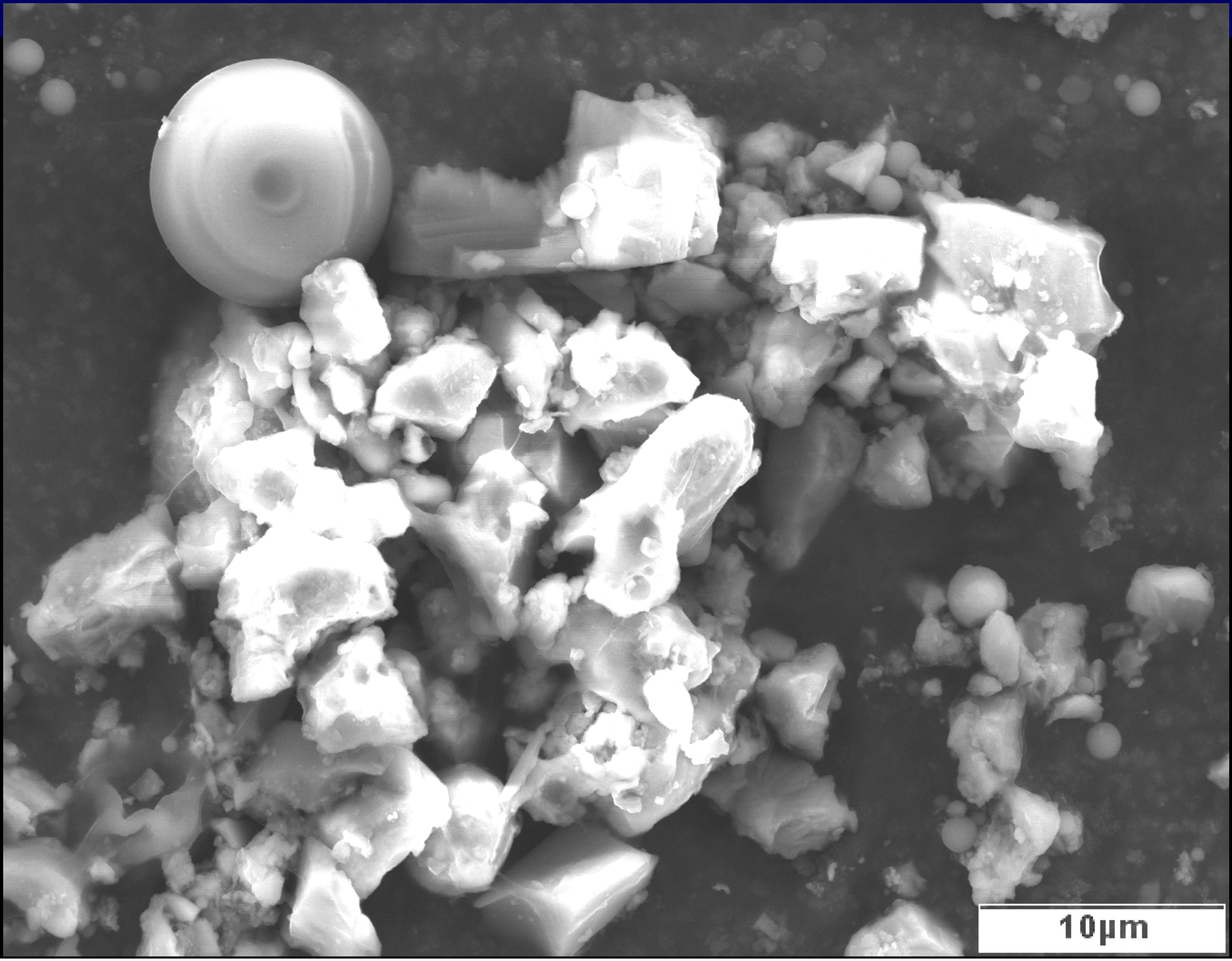
- Agglutinates are the major constituent in some mature lunar soils, irregularly shaped, heterogeneous, composed of mineral and glass fragments, and also contain implanted solar wind gases.
- **Grain size distribution:** The lunar samples returned by the Apollo and Luna missions indicate the regolith to be:

  ~ 20 wt%, of < 20 μm

  ~ 10 wt %, of < 10 μm

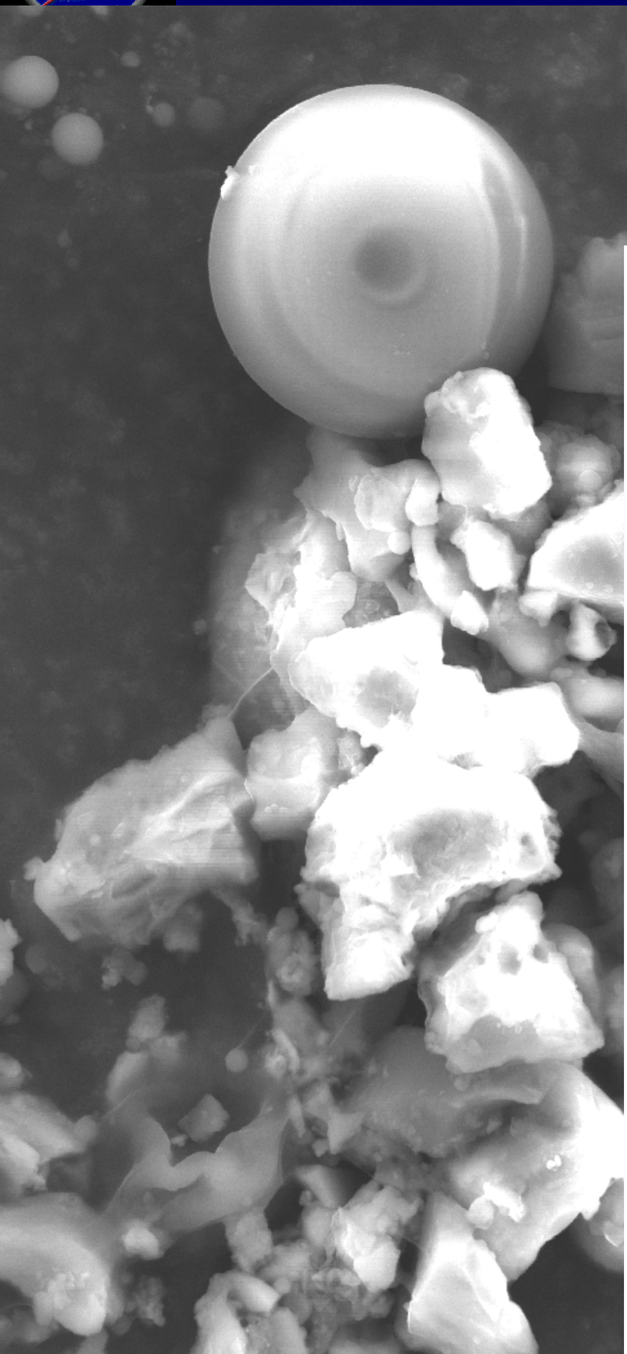
  Smaller fraction of sub-micron size grains.

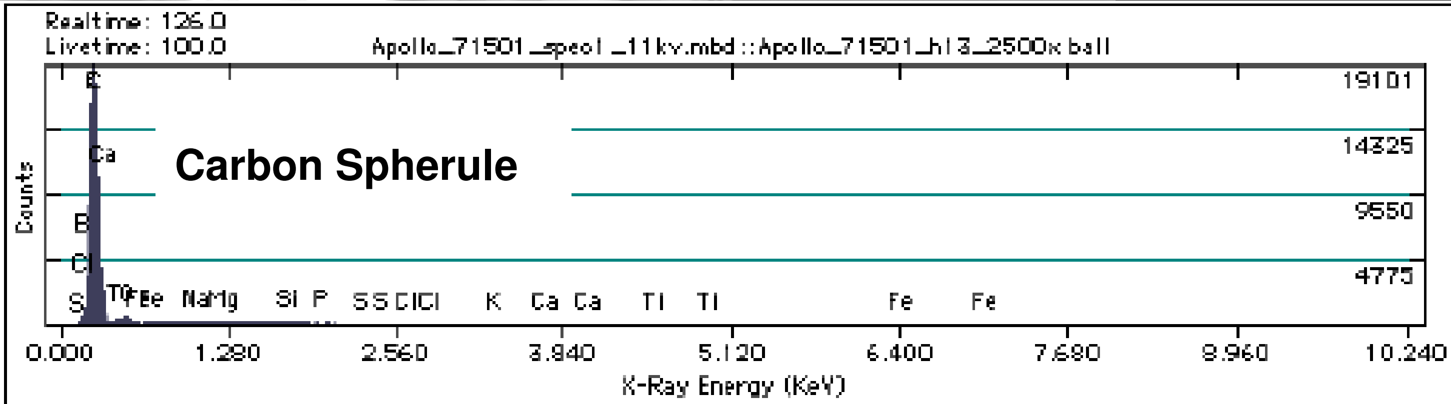
FESEM Image of Apollo-17 Grains



A. Micro regolith breccia with high Carbon sphere

FESEM Image of Apollo-17 Grains





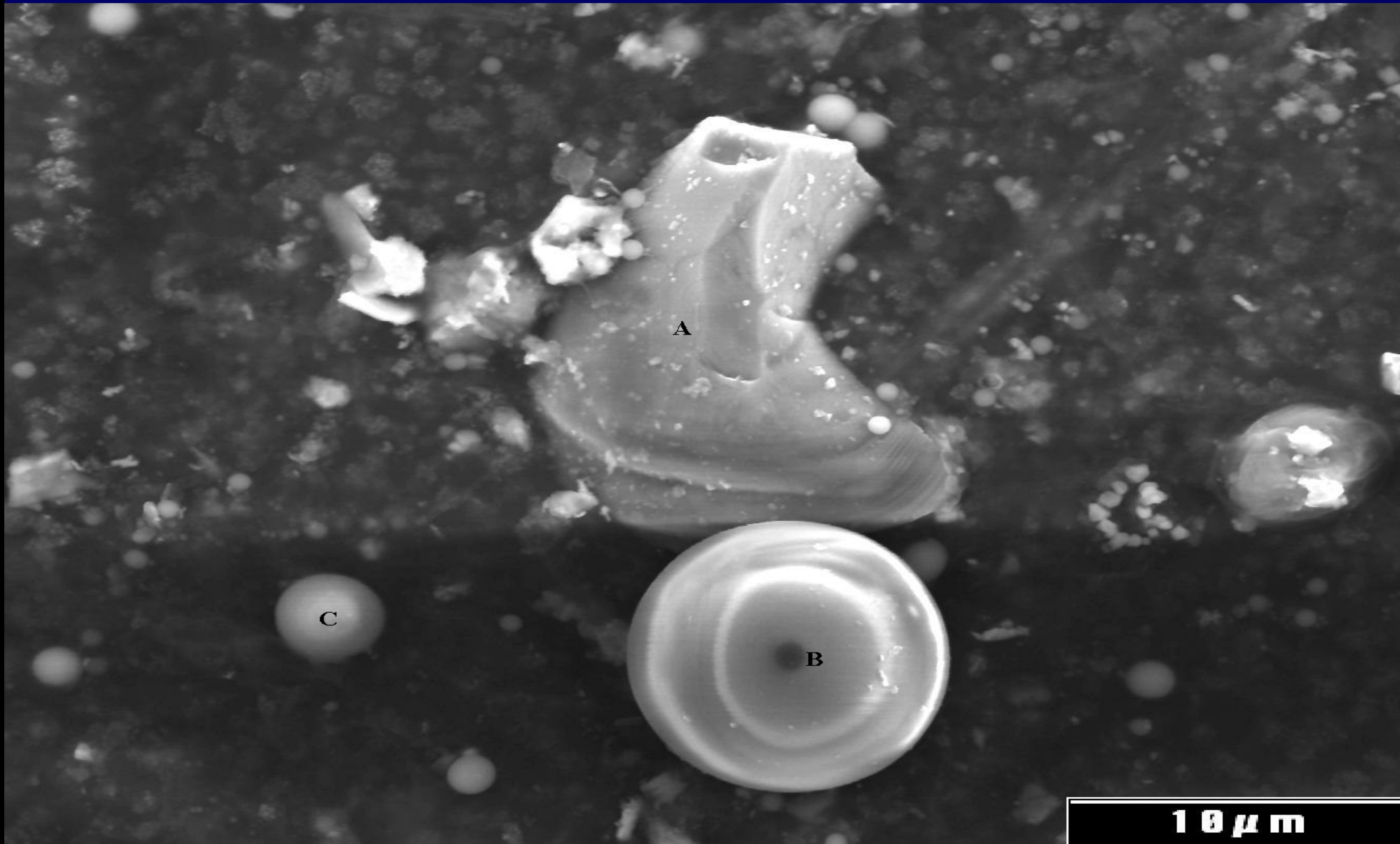
Quantitative Results for Apollo_71501_h13_2500x ball
Analysis: Bulk Method: Standardless
Acquired 12-Aug-2005, 11.0 KeV @10 eV/channel

Element	Weight %	Std. Dev.	MDL	Atomic %	k-Ratio	Intensities
B	6.34	1.14	0.02	7.15	0.0518	2640.6
C	85.76	1.98	0.03	87.09	0.6018	107952.0
N	1.86	0.60	0.76	1.62	0.0045	1092.6
O	4.42	1.03	0.36	3.37	0.0140	4009.6
Na ?	0.49	0.18	0.90	0.26	0.0035	1366.7
Mg ?	0.36	0.13	0.90	0.18	0.0029	1188.3
Al ?	0.30	0.11	0.96	0.13	0.0025	957.2
Si ?	0.33	0.12	0.82	0.14	0.0030	1092.2
P ?	0.15	0.06	1.35	0.06	0.0014	450.8
S ?	0.00	0.00	0.64	0.00	0.0000	0.2
Cl ?	0.00	0.00	0.72	0.00	0.0000	0.2
K ?	0.00	0.00	0.83	0.00	0.0000	0.2
Ca ?	0.00	0.00	0.86	0.00	0.0000	0.2
Ti ?	0.00	0.00	1.20	0.00	0.0000	0.2
Fe ?	0.00	0.00	2.12	0.00	0.0000	0.2
Total	100.00					

? These elements are statistically insignificant.

A. EDS Spot Spectrum at center of high carbon sphere

FESEM Image of Apollo-17 Grains



A. **Silicon carbide particle; B. 10 µ diameter spherical particle with 92.5% carbon content.**

C. Smaller 3 µ diameter spherical silicate particle to left of large sphere.

D. Dark spot on top of 10 µ diameter spherical particle shows 95.2% Carbon

FESEM Images of Apollo-17 Grains

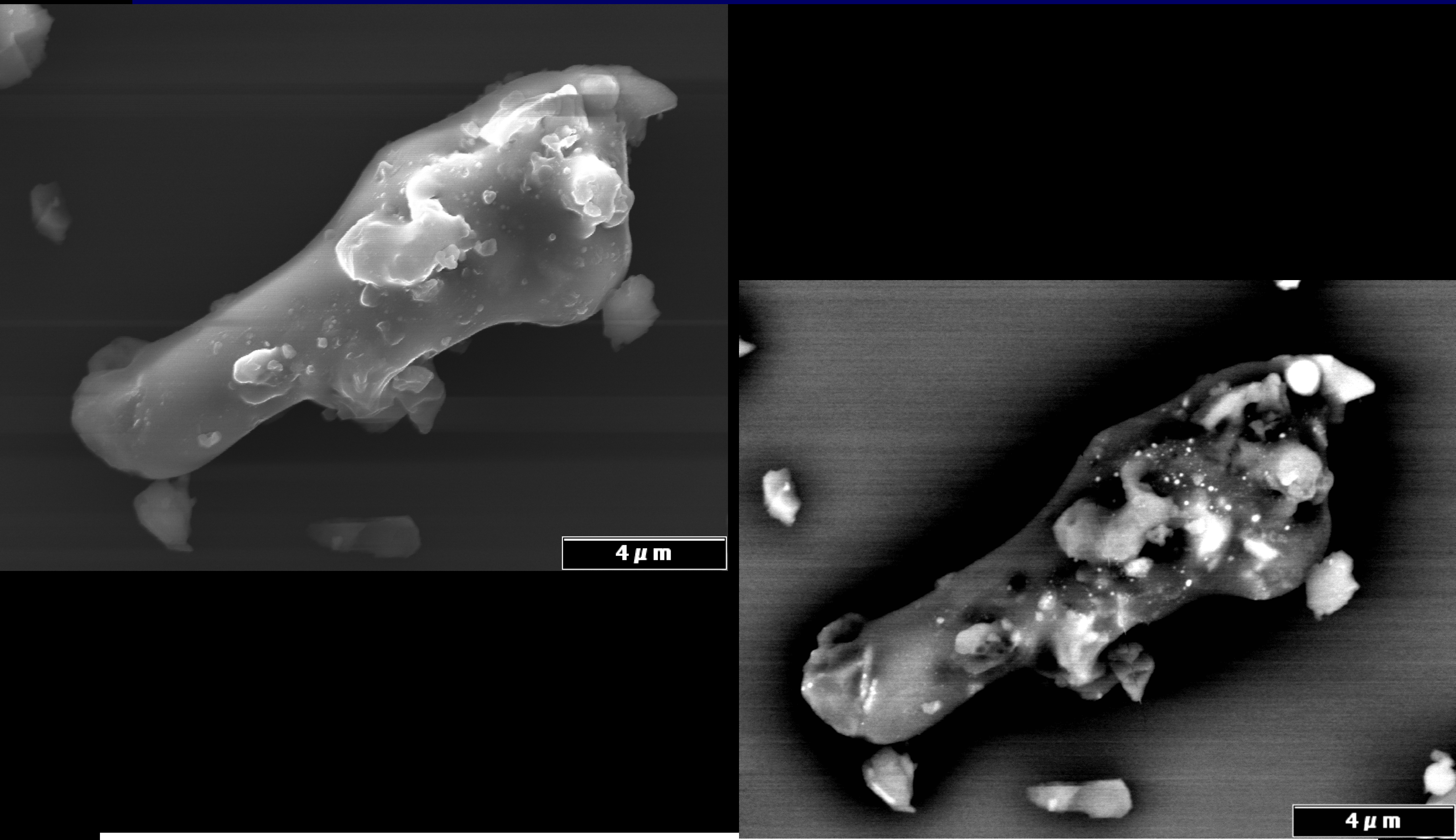
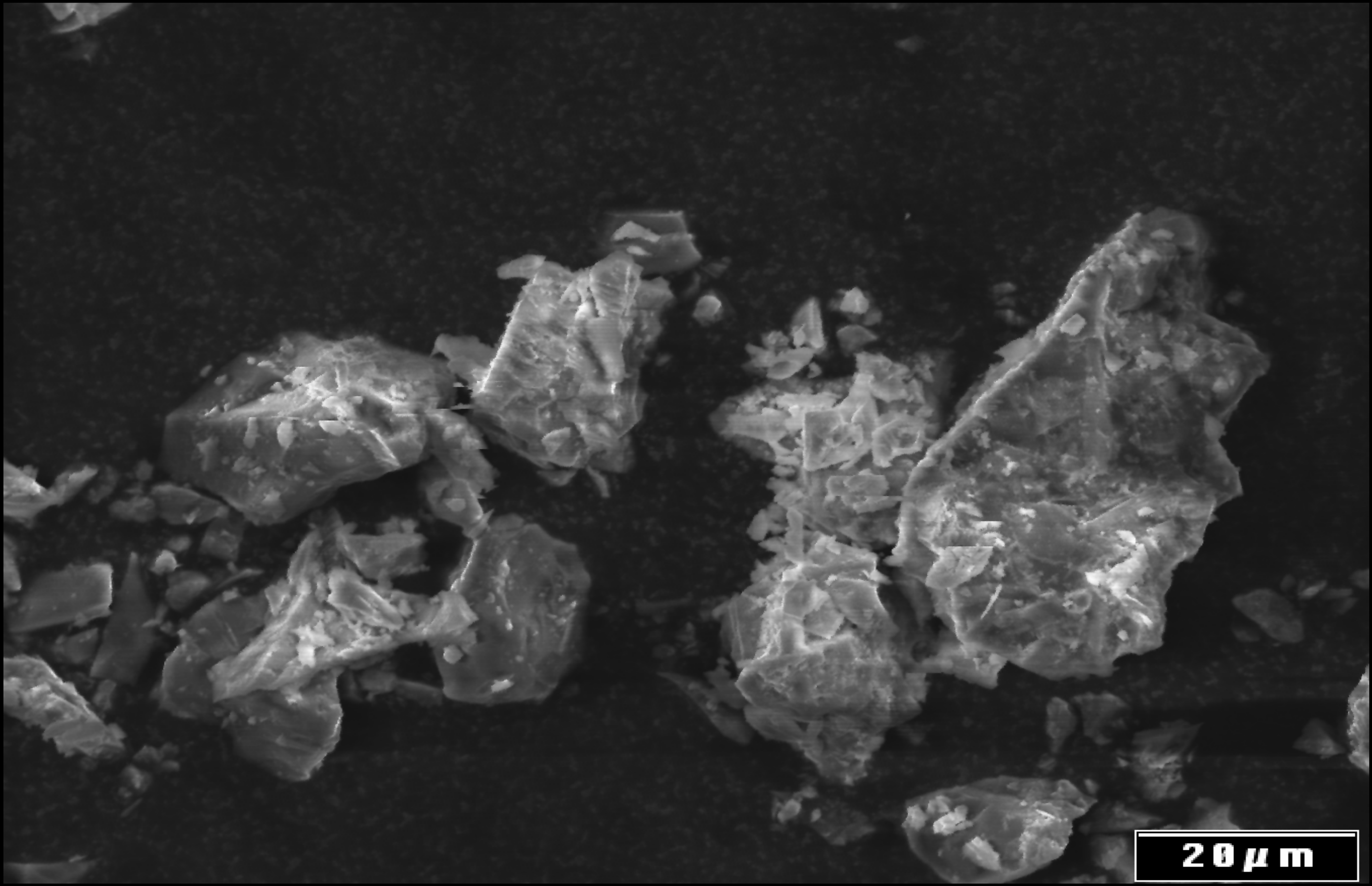


Fig. A. Secondary Image; B. Backscatter Image

FESEM Image of JSC-1 Simulant Dust Grains



Lunar Dust Composition

Chemical Composition

Compositior	% wt
SiO_2	47.3
TiO_2	1.6
Al_2O_3	17.8
Fe_2O_3	0
FeO	10.5
MgO	9.6
CaO	11.4
Na_2O	0.7
K_2O	0.6
MnO	0.1
Cr_2O_3	0.2
P_2O_5	0

Elemental Analysis

Element	At. Wt.	Wt. %	Atomic %
O	16	44.05	60.71
Si	28.1	22.12	17.36
Ti	47.9	0.96	0.44
Al	27	9.42	7.70
Fe	55.8	8.16	3.23
Mg	24.3	5.79	5.25
Ca	40.1	8.15	4.48
Na	23	0.52	0.50
K	39.1	0.43	0.24
Mn	54.9	0.08	0.03
Cr	52	0.14	0.06
P	31	0.00	0.00

Lunar Dust Charging Processes

- Charging by photoelectric emissions,by UV radiation at wavelengths < 200 nm on the day side, leading to positively charged grains.

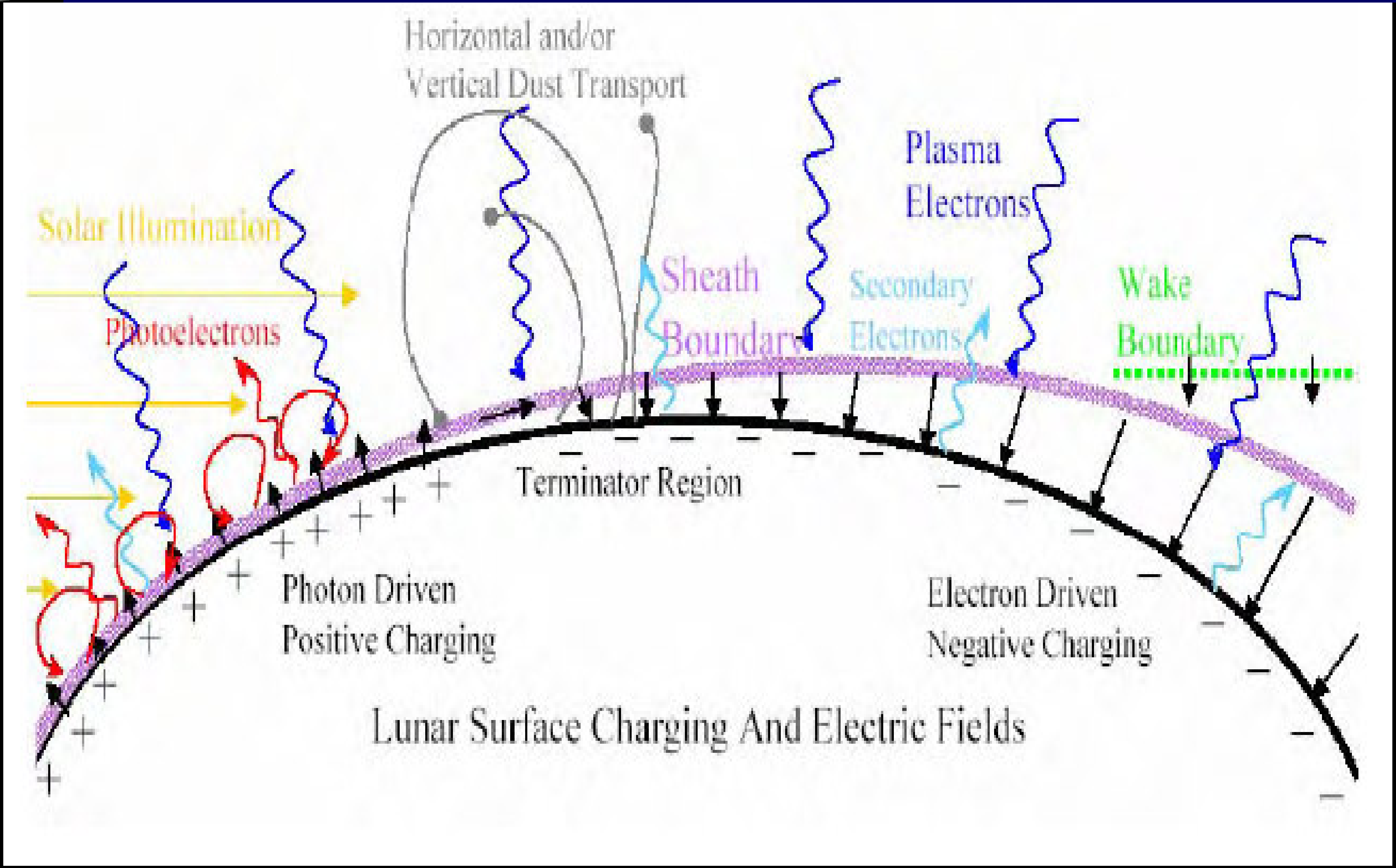
- Electron or ion collisions on the night side, generally leading to negatively charged grains with low energy electrons ((< 100 eV).

- Secondary electron emissions by solar wind electrons with sufficiently high energy may produce positively charged grains.

- Triboelectric charging of dust grains by contact charging process in which electrons are transferred from a solid material with high work function to one with a lower work function.

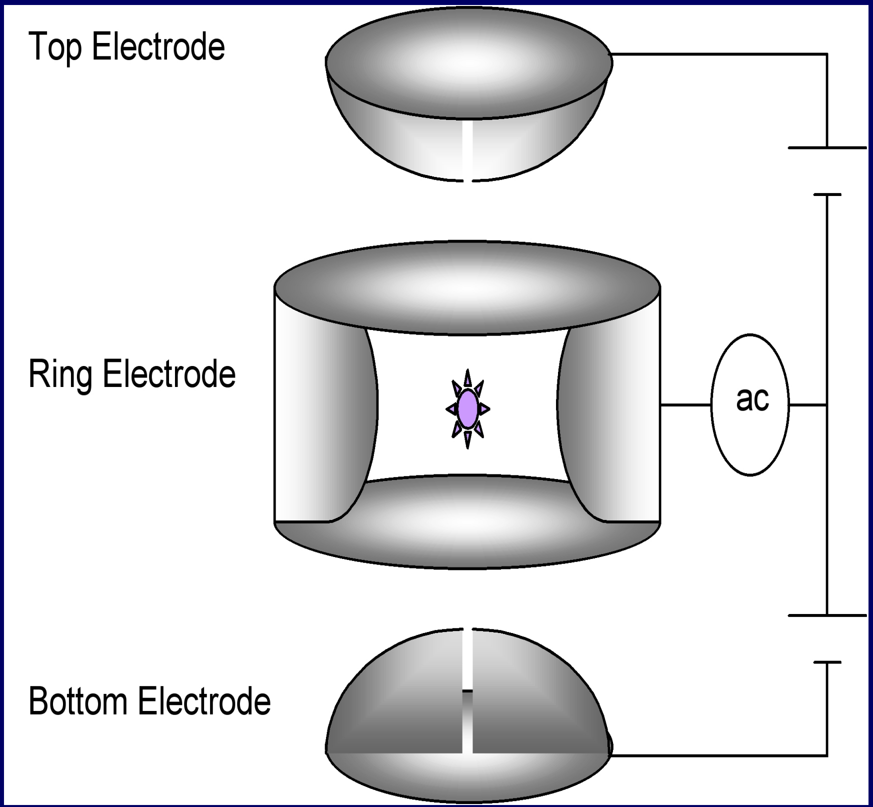
- Large electric fields created over the terminator are assumed to produce dust clouds that are observed as a glow produced by sunlight scattered over the horizon.

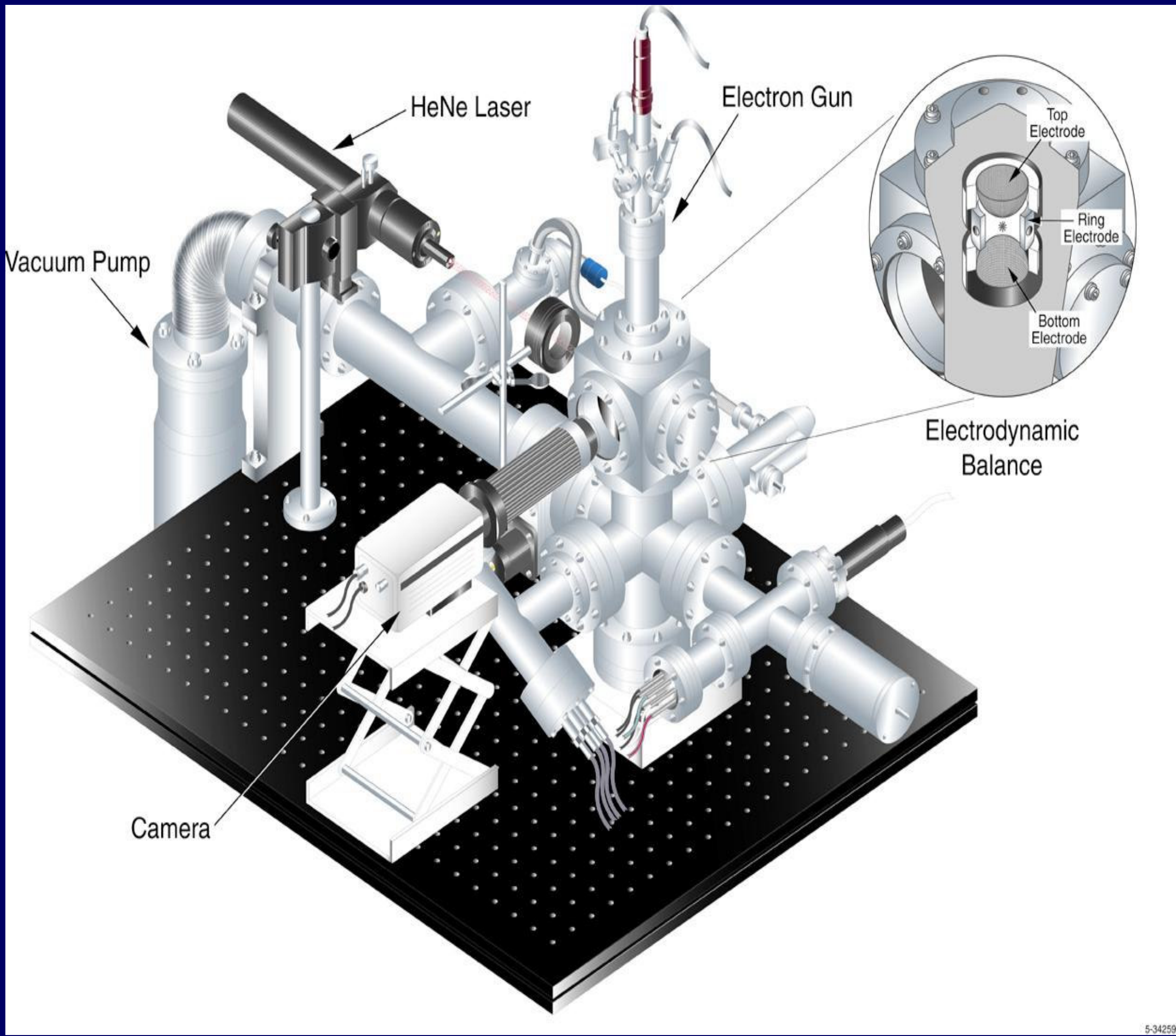
Lunar Electrostatic Environment



From, Stubbs et al., 2006

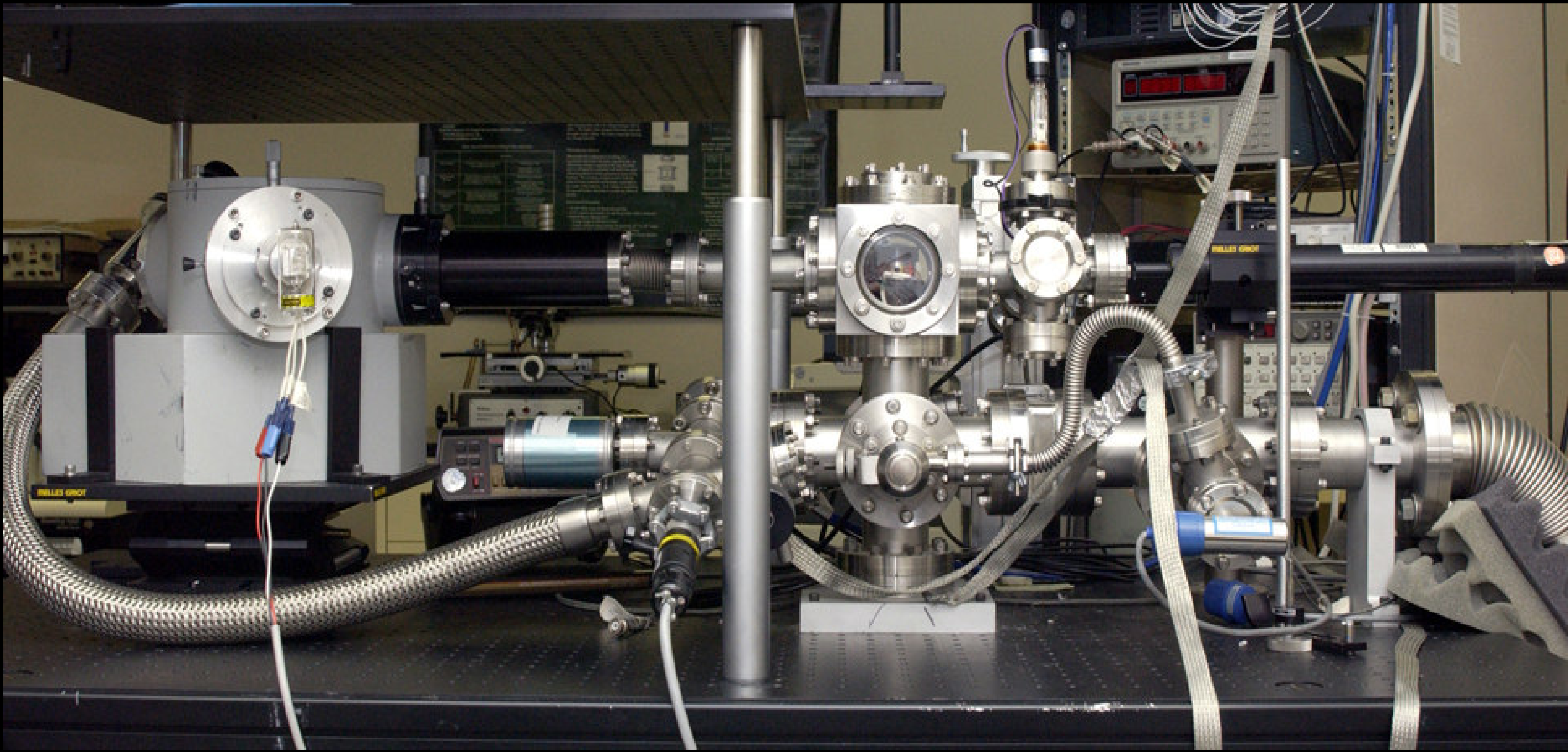
Laboratory Facility for Measurements of Optical and Physical Properties of Individual Dust Grains: Electrodynamic Balance





$$\frac{1}{2}r^2 = z^2 \pm z_o^2$$

A Pictorial View of the Electrodynamic Balance



Measuring the Grain Charge and Mass

- **Measure q/m ratio ~ 1/ V_{dc}**

Determine size (D) and mass m with 'spring point' stability measurements involving field factor (β) and drag parameter (ξ).

$$\beta = \frac{g}{C_o z_o \Omega^2} \frac{V_{ac}}{V_{dc}}$$

- **Calculate the particle effective diameter, mass and charge**

(Δm ~ 10^{-12}-10^{-14} g, Δ q ~ single electron.

- **Calculate effective surface potential ϕ_s**

- **P ~10^{-5}-10^{-8} Torr**

$$\frac{q}{m} = \frac{g z_o}{2 C_o V_{dc}}$$

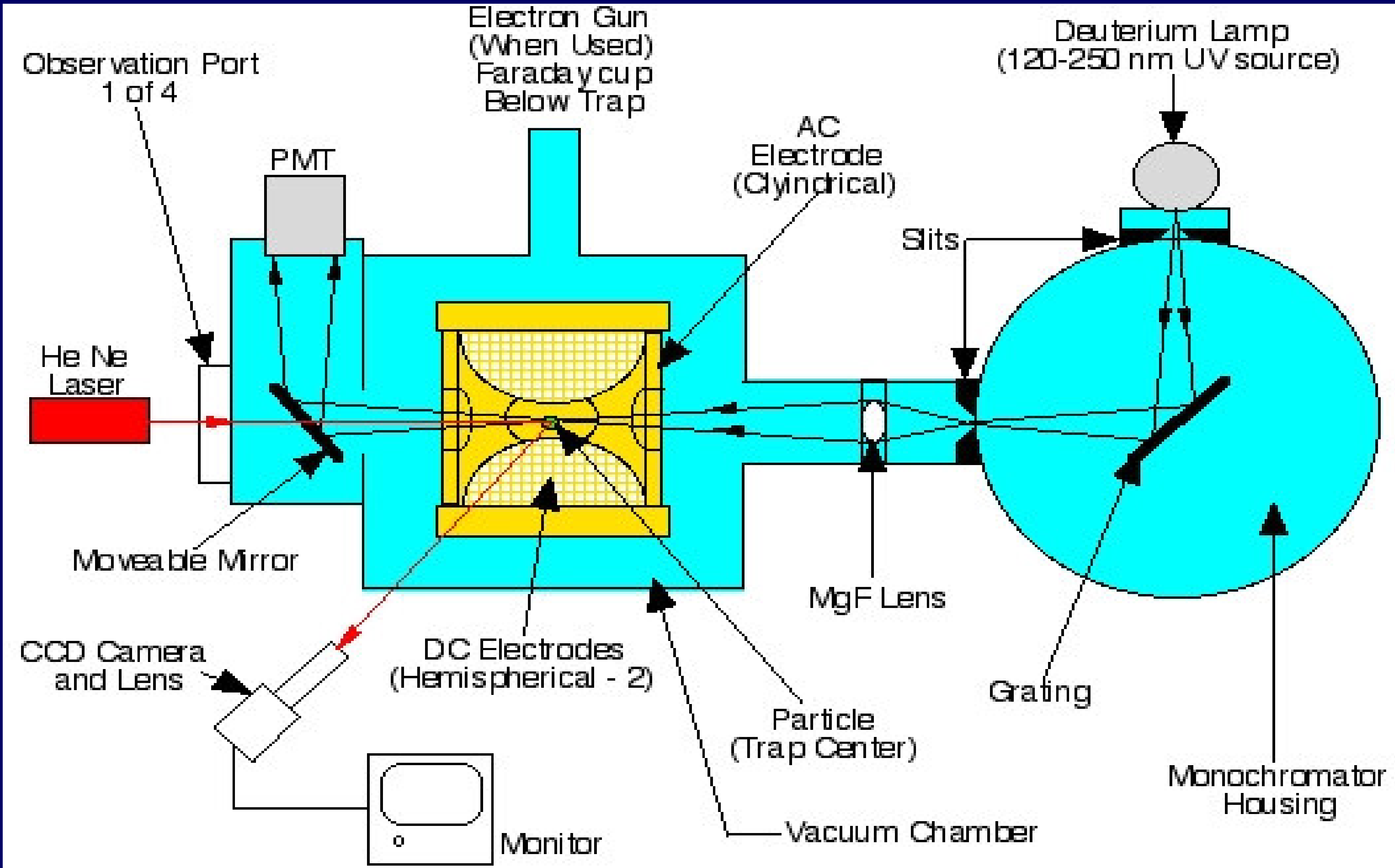
$$\xi = \kappa / 2 = \frac{18\eta}{\rho \Omega D^2}$$

$$\phi_s = \frac{q}{4 \pi \varepsilon_o r}$$

Experimental Procedure

- **Positively or negatively charged particles selected from bins of various size ranges are injected into the trap.**
- **A controlled evacuation procedure is started while keeping an individual particle stably trapped.**
- **Viscous drag measurements are performed at pressures of ~ 1 to 5 torr to determine the "effective" diameter of the particle.**
- **The pressure is reduced to ~ 10^{-4} to 10^{-5} torr for the desired measurements.**

Experimental Setup for Photoelectric Emission Measurements



Dust Charging by Photoelectric Emissions

- Photoelectric Efficiency = Photoelectrons emitted/Photons incident
- Photoelectric Yield = Photoelectrons emitted/Photons absorbed
- No rigorous theory or experimental data available for the yields of individual micron size dust grains.
- Current theoretical models predict conflicting values for photoelectric emissions for individual sub-micron size dust grains: (a) Larger than the bulk values (Astrophys. Lit.)

  (b) Smaller than the bulk values (Atomic cluster theory and experiments).
- First photoelectric emission measurements on individual dust grains presented here.

Measuring Photoelectric Efficiency and Yield

Number of photons/sec incident on a dust grain:

$$n_d^{ph} = \frac{i_{pmt}(\lambda)}{e\eta_q(\lambda)GR} \cdot \frac{D_{\mu m}^2}{w_e^2(\lambda)} = 1.73\times10^{16}\frac{i_{pmt}(\lambda)}{\eta_q(\lambda)} \cdot \frac{D_{\mu m}^2}{w_e^2(\lambda)}$$

Number of electrons/sec ejected from the dust grain::

$$n_d^e(\phi_s) = \frac{i_d}{e} = \frac{1}{e}\frac{\partial q}{\partial t}$$

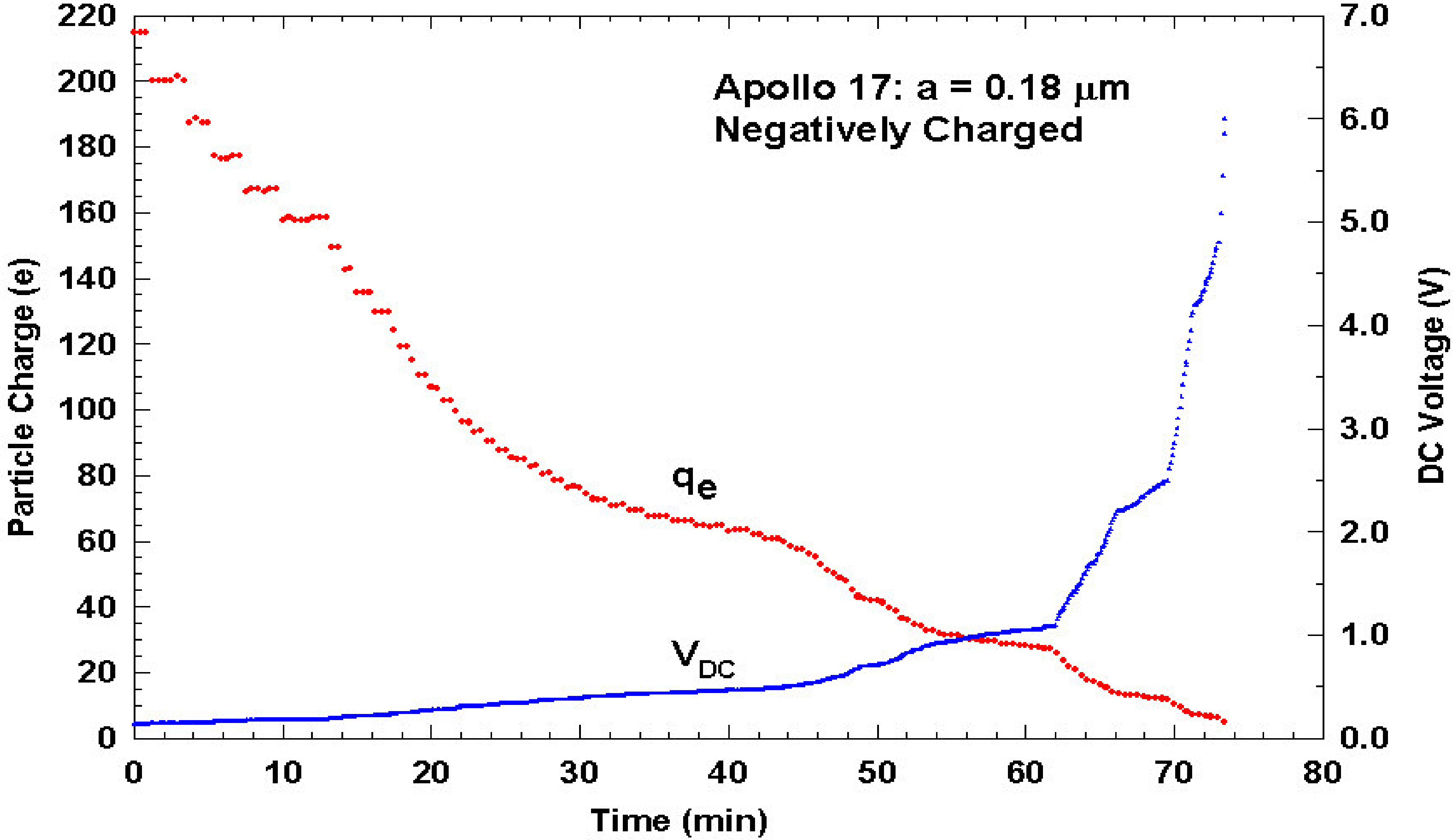
Photoelectric Efficiency:

$$E_{pe} = \frac{n_d^e(\phi_s)}{n_d^{ph}}$$

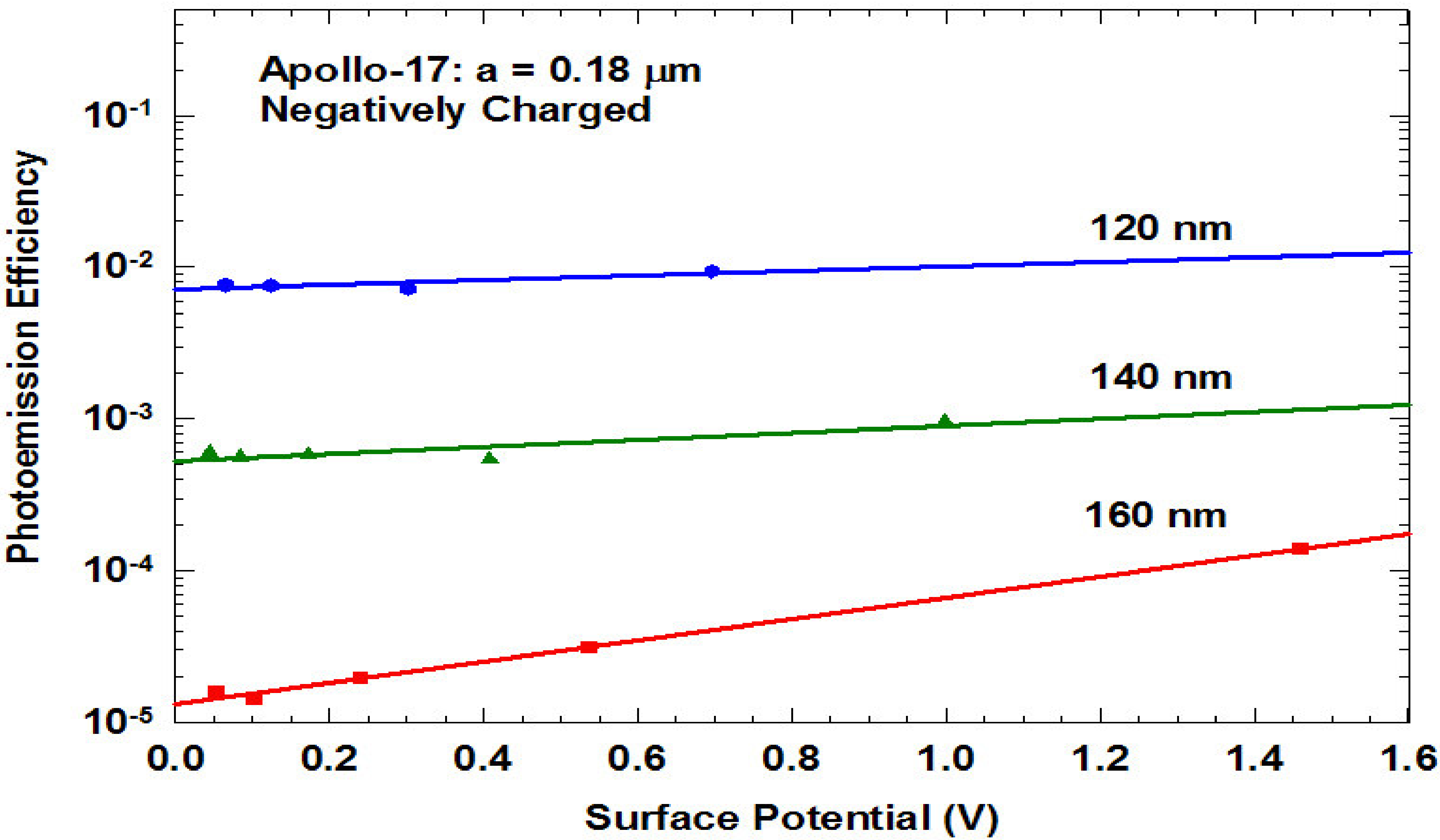
Photoelectric Yield:

$$Y = E_{pe}/Q_{abs} = \frac{n_d^e(\phi_s \to 0)}{n_d^{ph}.Q_{abs}}$$

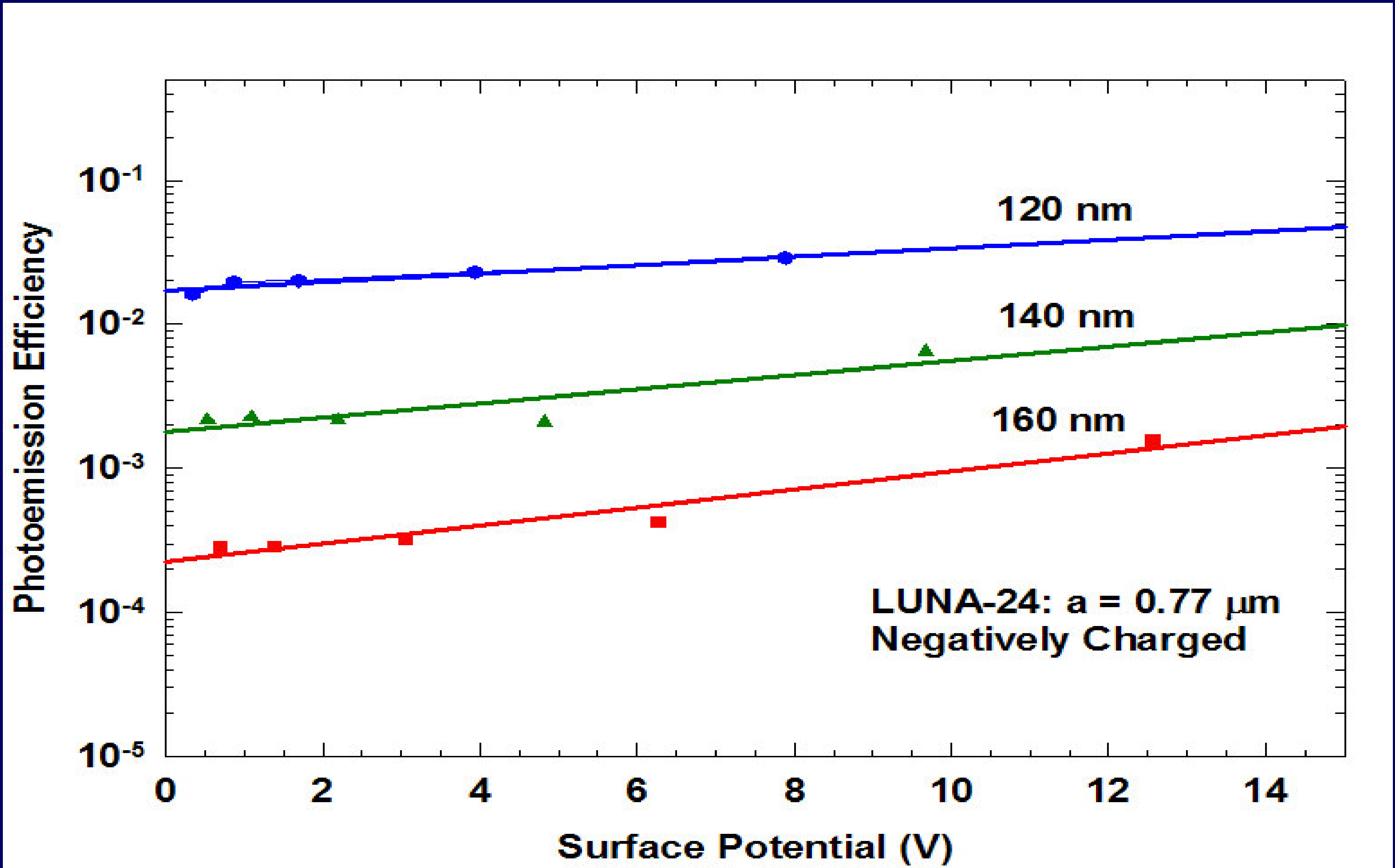
Discharging of a Negatively Charged Apollo-17 Grain with UV



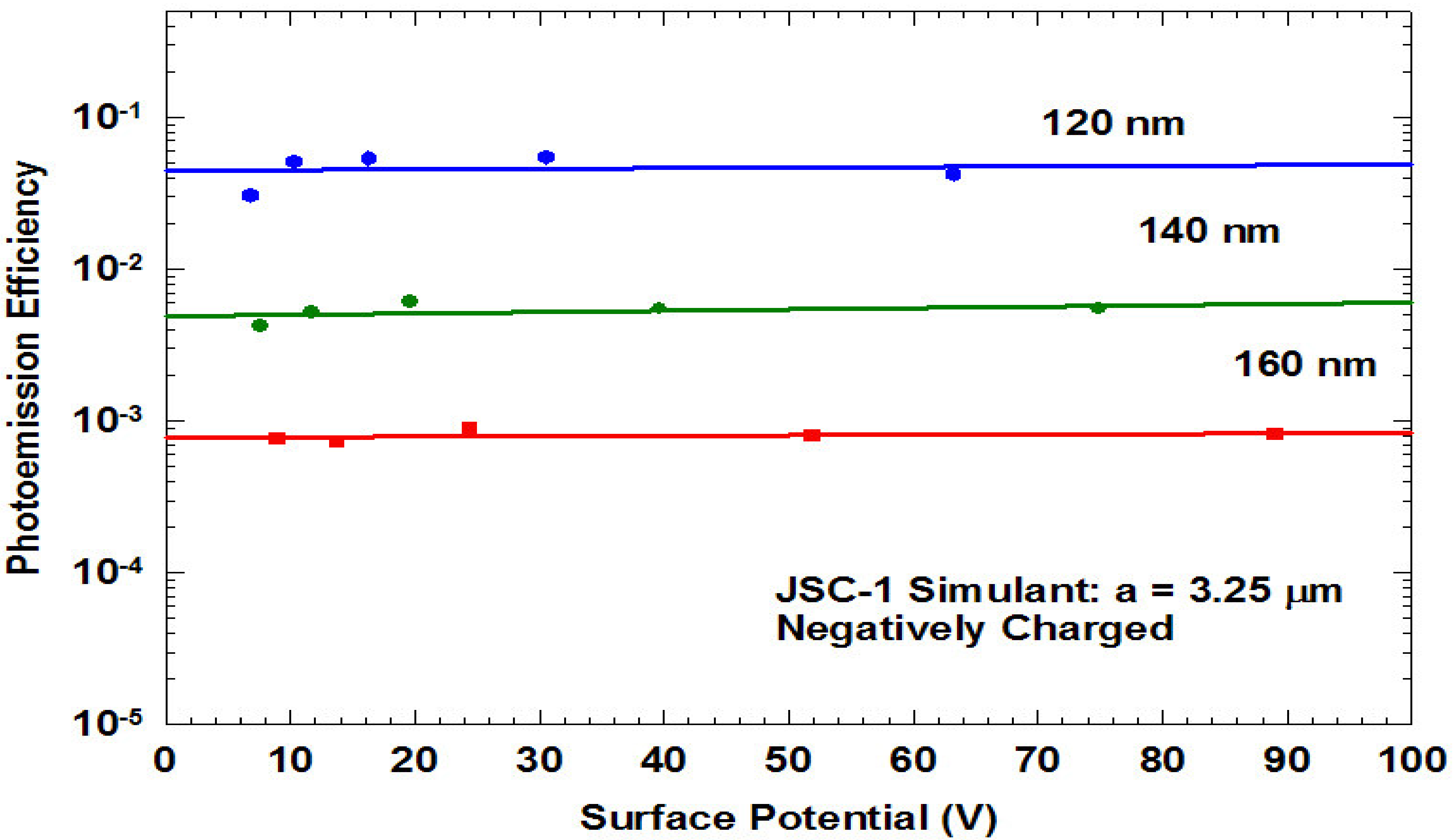
UV Photoelectric Efficiency Measurements on an Apollo 17 Dust Grain



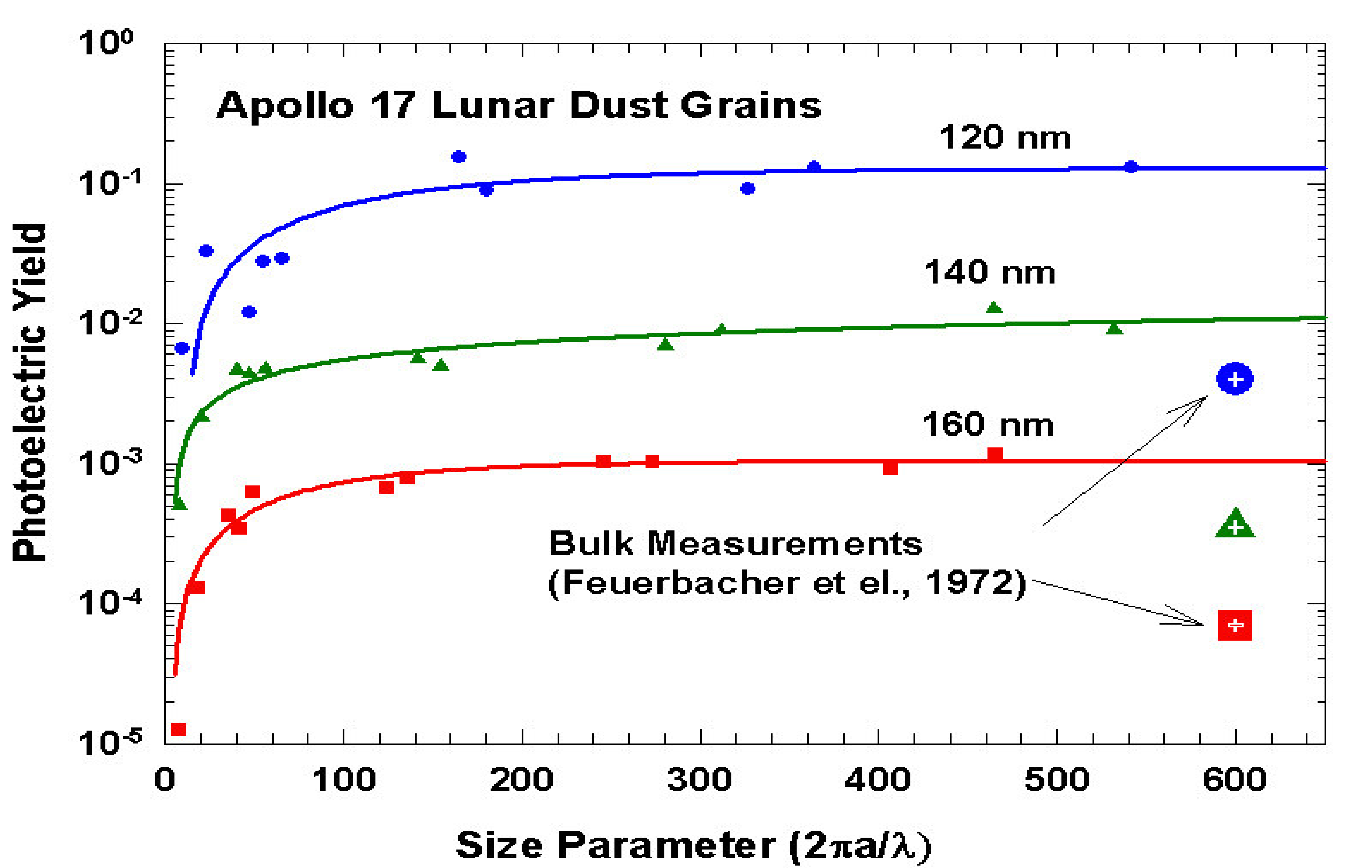
UV Photoelectric Efficiency Measurements on a Luna 24 Dust Grain



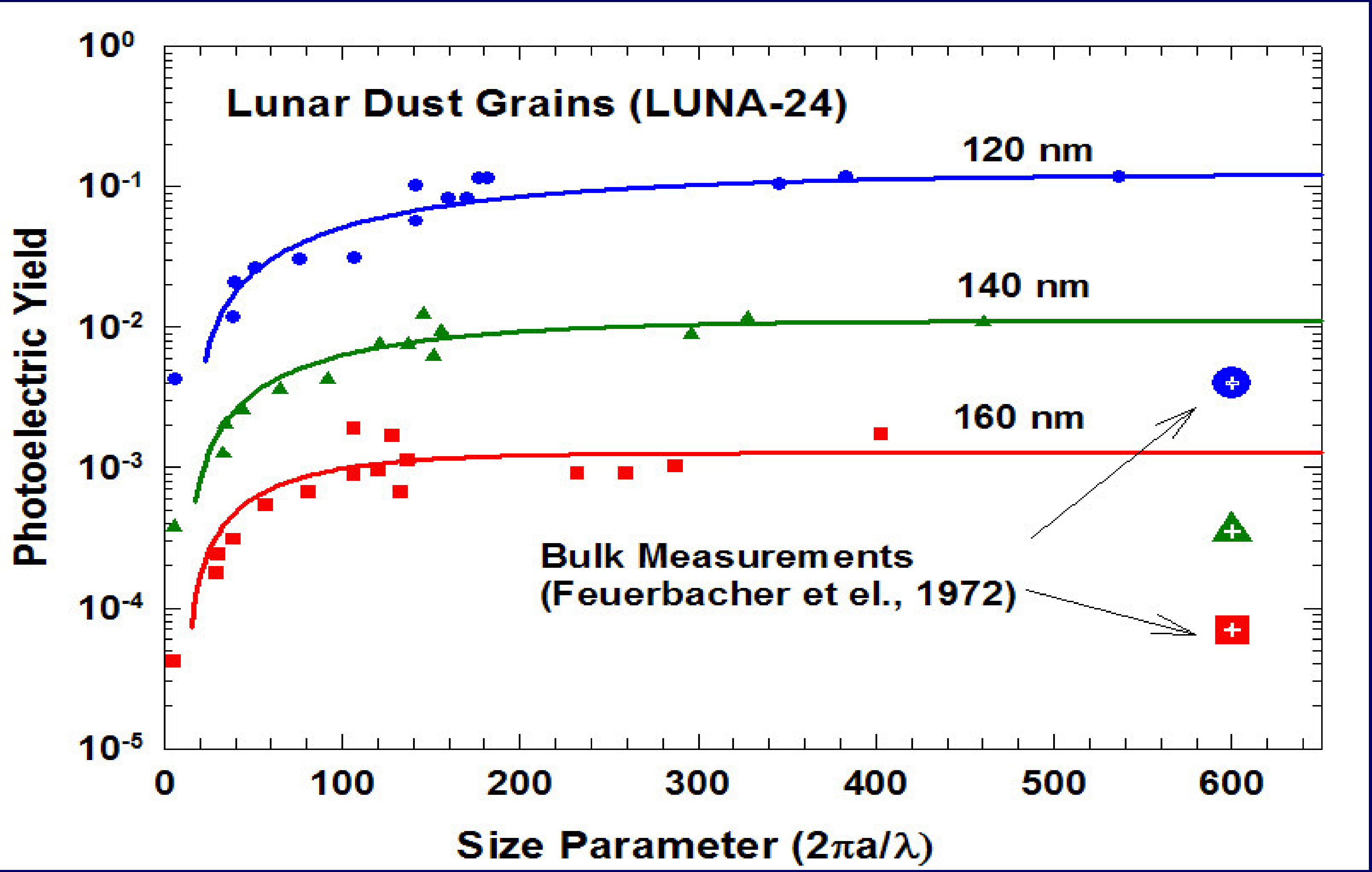
UV Photoelectric Efficiency Measurements on a JSC-1 Simulant Dust Grain



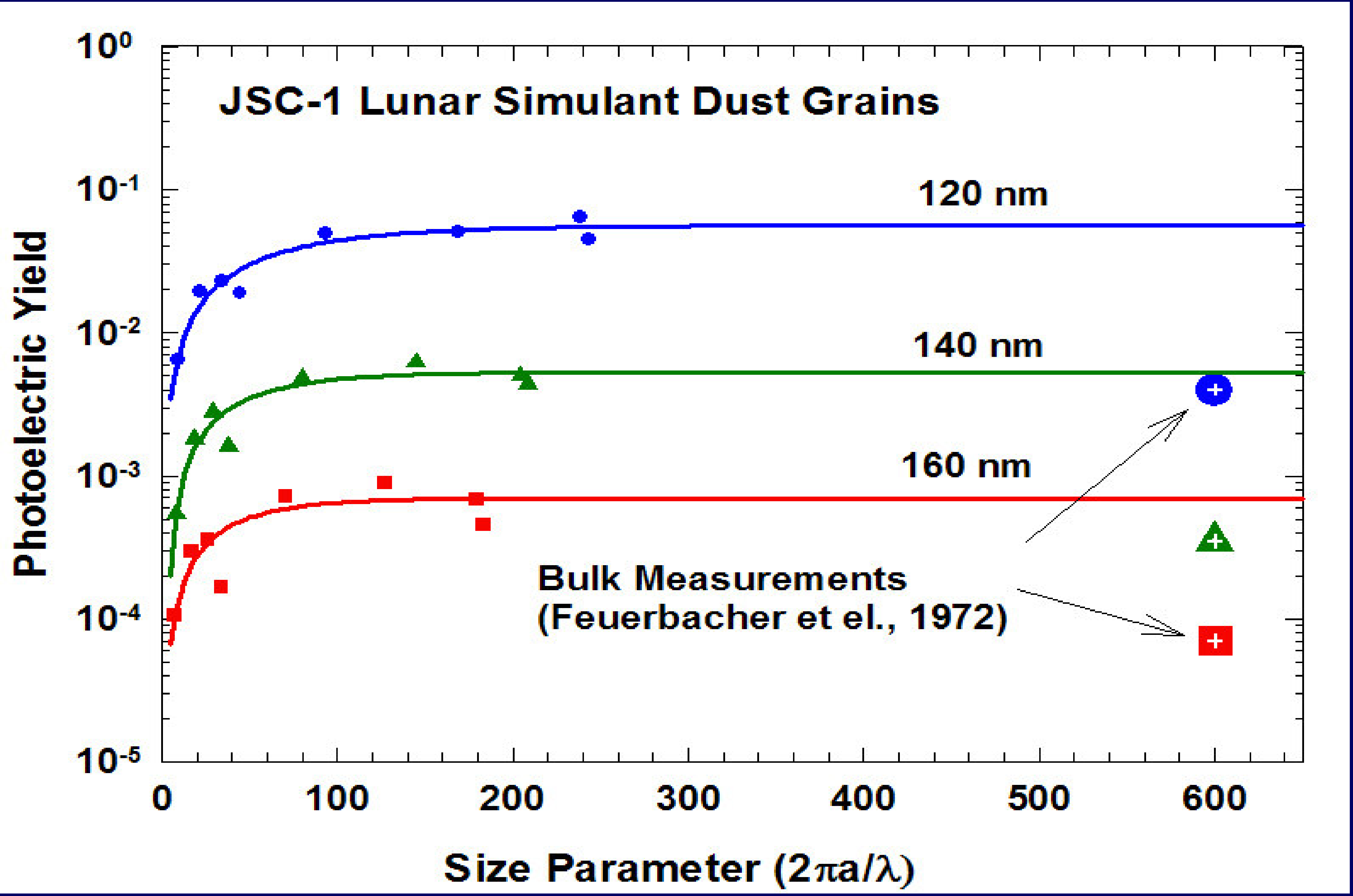
UV Photoelectric Yield Measurements of Apollo 17 Lunar Dust Grains



UV Photoelectric Yield Measurements of Luna 24 Dust Grains



UV Photoelectric Yield Measurements of JSC-1 Lunar Simulant Dust Grains



Conclusions on Photoelectric Charging

- First measurements of photoelectric yields of individual Apollo-17, Luna 24, and JSC-1 simulant dust grains of ~ 0.1 to 8 micron radii have been obtained.
- Measurements indicate a size dependence of the yields, increasing with grain size to asymptotic values by an order of magnitude.
- The asymptotic values of the yields are higher than the bulk values reported in the literature by factors of ~ 15-35.
- The yields for the Apollo 17 dust grains are similar to those for Luna-24 dust grains.
- The JSC-1 yields are lower than the Apollo 17 dust grains by factors of ~ 2.

Future Work on Lunar Dust Issues

1. Measure lunar dust charging properties by low energy electrons simulating the solar wind.
2. Conduct a comparative study of dust charging by photoelectric emissions and electron beams on individual dust grains selected from sample returns from lunar missions Apollo 11, 12, 14, 15, 16, and 17.
3. Evaluate the effect of lunar temperature cycle on dust charging properties, employing the cryogenic facility under development.
4. Measure the UV complex refractive indices of lunar dust grains by scattering measurements.
5. Determine infrared optical properties of lunar dust grains for characterization by remote sensing techniques.

Future Collaborative Plans with other Groups on Lunar Dust Issues

1. Develop dust **levitation and transportation models** for evaluation of various dust mitigation strategies.

2. Conduct experiments on dust charging, electrostatic fields, and levitation with UV radiation and electron beams on **dust in a vacuum chamber.**

3. Evaluate and devise **dust mitigating strategies** suitable for various applications and situations in the lunar environment. Current proposals:

   (a) Magnetic devices (Larry Taylor)

   (b) "Electric curtain" with high voltage electrodes to produce a traveling wave across a transparent surface (Carlos Calle)

Future Collaborative Plans with other Groups on Lunar Dust Issues

DUST MEASUREMENTS ON THE MOON

1. **Measurements of:**

   (i) Dust grain density

   (ii) Dust grain size distribution

   (iii) Dust grain composition

   (iv) Electrostatic fields, and electron density in the sheath

2. **Instruments for above measurements:**

   (a) Near surface in-situ measurements

   (b) High altitude remote sensing measurements

End.

Thank you!